

# Genetically Modified Food: Knowledge and Attitude of Teachers and Students

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**Abstract** The concepts behind the technology of genetic modification of organisms and its applications are complex. A diverse range of opinions, public concern and considerable media interest accompanies the subject. This study explores the knowledge and attitudes of science teachers and senior secondary biology students about the application of a rapidly expanding technology, genetic engineering, to food production. The results indicated significant difference in understanding of concepts related with genetically engineered food stuffs between teachers and students. The most common ideas about genetically modified food were that cross bred plants and genetically modified plants are not same, GM organisms are produced by inserting a foreign gene into a plant or animal and are high yielding. More teachers thought that genetically engineered food stuffs were unsafe for the environment. Both teachers and students showed number of misconceptions, for example, the pesticidal proteins produced by GM organisms have indirect effects through bioaccumulation, induces production of allergic proteins, genetic engineering is production of new genes, GM plants are leaky sieves and that transgenes are more likely to introgress into wild species than mutated species. In general, more students saw benefits while teachers were cautious about the advantages of genetically engineered food stuffs.

**Keywords** Genetic engineering · Herbicide resistant · Biodiversity · Invasive species · Transgenes · Bioaccumulation and allergic proteins

## Introduction

There is little doubt that history will record, as a major feature of the beginning years of this century, the development and application of ‘new biology’. Just as the 1940s and 1950s were seen as the dawn of the nuclear age; 1960s, 1970 and 1980s as the dawn of the molecular genetics, so the late 1990s and early 2000s will be viewed as the time when new biotechnology was applied in variety of ways; the use of genetically modified organisms for drug synthesis, gene therapy and the production of genetically engineered food stuffs.

Biotechnology and in particular genetic engineering is poised to become one of the most important scientific revolutions of the twenty first century. Sequencing of genomes will become commonplace and the implications of this science and its resultant technologies will dramatically alter the way we fight diseases, grow crops and feed our population (Kirkpatrick et al. 2002).

Many science education researchers advocate that biotechnology instruction raises important political, economic, ethical and educational questions. Members of society must receive an effective education in order to appreciate these questions and their answers (Bird Stewart 1987; Stewart and Van Kirk 1990; Garton 1992; Lewis and Wood-Robinson 2000 and Marbach-Ad 2001). There have been a number of investigations of public attitudes to biotechnology in agriculture or food (Hoban and Kendall 1992; Marlier 1992; Macer 1994; Zechenedorf 1994; Hallman 1996 and Hoban 1997). These researchers have mapped consumer acceptance of biotechnology products. In general, attitudes to biotechnology depend upon the type of organism involved. Micro-organism and plant applications are well accepted. Animal applications are less well accepted with only certain applications, such as the

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production of medicines and the development of resistance to disease considered being very acceptable.

Research has shown that high school students typically lack a coherent view of some genetic concepts and their relationships when studying science (Lewis and Wood-Robinson 2000). In the absence of education on biotechnology subject matter, public unease has increased concurrently with the production and marketing of genetically modified foods (Marchant and Marchant 1999). The GMF controversy generates a great deal of media attention, and has direct relevance to the daily lives of students and teachers because we are all eating GMF. The GMF controversy involves a complex set of tradeoffs, because it is difficult to predict, the long-term impact of GMF, and because different genetically modified crops have different risks and benefits. Not including the ethical question, there are three main themes of tradeoffs in the controversy:

- *Human Health:* Genetic engineering of food has been touted as a way of growing enough food for an increasing world population, and improving the nutrients intake of population at risk for deficiencies—as in case of golden rice, which contains a precursor to vitamin-A (Ye et al. 2000). Genetic engineering also has the power to remove allergens in food, and while research shows that this is feasible (Tada et al. 1996) critics contend that genetic engineering, by allowing us to introduce from completely unrelated species, could result in the introduction of novel allergens into the human food chain (Holdredge and Talbott 2001).
- *The Environment:* Proponents of genetic engineering believe that crops engineered to express their own pesticides could reduce the use of chemical on crops (Thayer 1999). Others are concerned that these crops may increase insecticide resistance in insect pests, lead to herbicide resistance in weeds, and many harm beneficial insects such as Monarch Butterflies (Losey et al. 1999; Wolfenbarger and Phifer 2000).
- *Economics:* Disease resistant crops could benefit farmers; for example, a genetically modified disease-resistant papaya variety is credited with saving the livelihood of Hawaiian papaya farmers whose crops were being destroyed by a virus (Yoon 1999). On the other hand, opponents point to increasing difficulties exporting GMF to certain countries, and to the risks of corporate control of agriculture.

There has been little research concerning senior secondary students' attitude and knowledge towards biotechnology. A survey by Lock and Miles (1993) asserts that knowledge of biotechnology among high school students is slight and reveals similarity between their responses and those of the general public. Garton (1992) asserts that students who develop an adequate understanding of the

concepts and processes involved in genetic engineering will be better able to understand subjects discussed in the media and be better prepared to participate in major decisions. Fisher (1992) and Kindfield (1992) believe it is important for teachers to emphasise the connection between genetics, biotechnology and everyday life in order for pupils to be able to deal with any ethical problems that may arise later in life. The present study used a questionnaire approach to examine the predominance of various ideas about the possible advantages and dangers of genetically engineered food stuffs. The respondents were science teachers as they prepare our students for technological citizenship and senior secondary students because they represent the upcoming generation of voting citizens and purchasers.

## Procedures

The present study aims to investigate the level of knowledge and attitude towards genetically modified food and the ideas about the risks and advantages related to it of the science teachers and senior secondary biology students. Randomly schools were identified in different cities of Rajasthan, UP, Punjab, Himachal Pradesh and Jammu and Kashmir. A questionnaire containing forty-one questions was designed having three sections. The sections A and B of the questionnaire are closed type. The section A contained fifteen questions in the form of statements, all of which are knowledge based. The section B contained twenty questions related with advantages and risks of the GMF of which thirteen were scientifically acceptable and seven were scientifically unorthodox statements interspersed at random. The section C of the questionnaire was open-ended type containing six questions dealing with the general feelings, perception about own level of knowledge and source of knowledge.

The questions of sections A and B comprised statements to which the teachers and students were offered three responses, 'I agree', 'I don't know' and 'I don't agree'. The respondents were asked to respond by ticking the appropriate box of their choice. The questionnaire was found to be satisfactory in that neither the teachers nor students indicated difficulty in answering the questionnaire items.

Questionnaires were completed under examination conditions, although no time limit was imposed. Respondents and institutions were assured of anonymity. The questionnaire was completed by 198 science teachers and 592 senior secondary biology students of class XII. Comparisons of the responses by teachers and students to different questions were made by Chi-square analysis using three categories ('affirm', 'neither' and 'reject').

## Results

### Responses of Teachers and Students to the Knowledge Based Statements About GM Food

The percentage of teachers and students giving different responses to the knowledge based questionnaire items of section-A are plotted graphically in Figs. 1 and 2. About three-fourth teachers (77.3%) and seven-tenth (69.8%) students did not agree that cross bred plants and genetically modified crops are the same. The results showed a significant difference between teachers and students in disapproving the statement ( $p < 0.01$ ). Majority of teachers and students (94% T and 83.9% S,  $p < 0.05$ ) have well understood the process of GM food production i.e. it is produced by the insertion of a foreign gene (s) into a plant or an animal to introduce a new characteristic or to alter the existing trait. About three-fifth of the teachers (60.7%) and a little more than half of the students (55.2%) believed that introduction of GM plants involve risk to the environment. At the same time there was a significant difference between teachers and students in affirming that GM food can be fatal to human (42% T and 45.8% S,  $p < 0.01$ ). More students agreed that using biotechnology on cattle to make meat more nutritious should be banned (40% T and 57.8% S,  $p < 0.01$ ). More than half of the teachers and students (56.7% T and 55.7% S) preferred GM tomato than kitchen garden grown tomato. Majority of teachers and less than three-fourth of the students expressed that GM food can save us from scarcity of food (84.7% T and 72.9% S,  $p < 0.01$ ) and

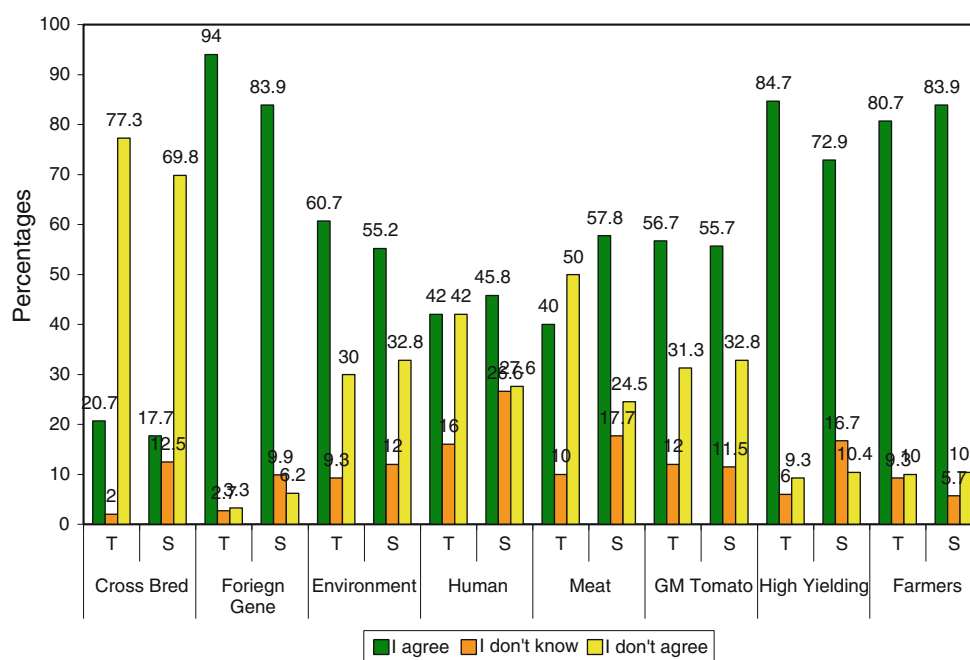
affirmed that GM crops are beneficial to farmers (80.7% T and 83.9% S).

In accepting the GM crops, containing genes of animal origin showed significant difference between teachers and students ( $p < 0.01$ ). More than half of the teachers (54.7%) and more than three-fifth of the students (64.6%) rejected the consumption of GM crops containing genes of animal origin being vegetarians. Interestingly, nearly three-fifth of the teachers and students (58.0% T and 58.3% S) expressed that taste of food can be improved through biotechnology. About two-fifth of teachers and students (42.0% T and 39.1% S,  $p < 0.01$ ) erroneously linked consumption of GM food with improvement of health. More teachers than the students agreed that GM food is imposing the risk of corporate control of agriculture (60.7% T and 46.9% S,  $p < 0.01$ ). Surprisingly, the results showed confusion about GM crops among teachers and students. More than half of the teachers (56.0%) accepted that production of GM crops is not a threat to biodiversity while only less than one-third of the students (30.2%) agreed to it showing significant difference ( $p < 0.01$ ). Majority of the teachers and more than three-fifth of the students agreed that genetic engineering should be used for production of better food (79.3% T and 66.1% S,  $p < 0.05$ ) but rejected out rightly the use of human genes for it (65.3% T and 67.7% S).

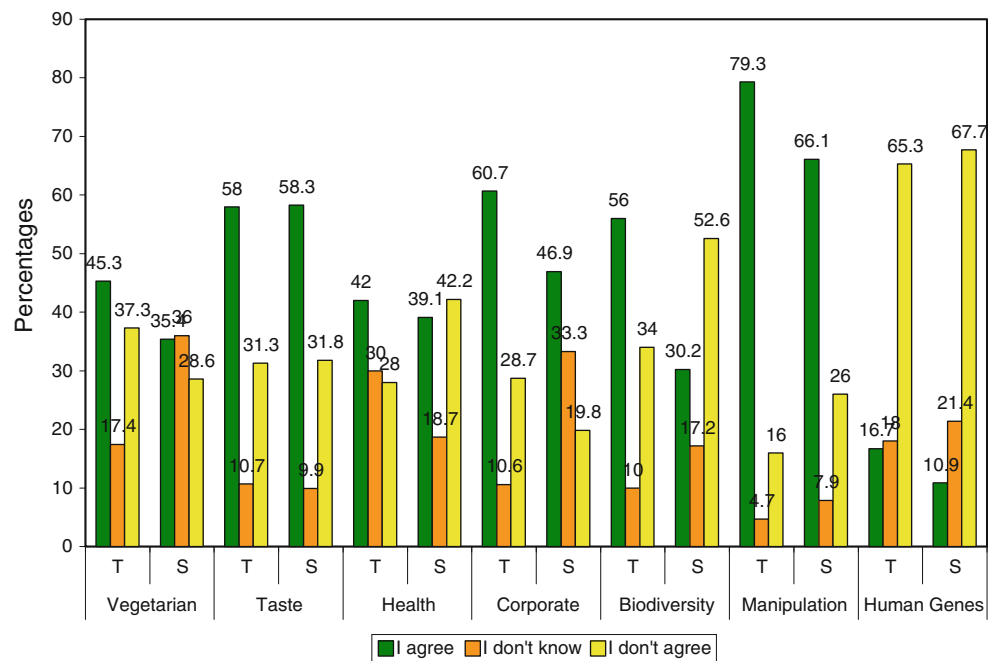
### Responses of Teachers and Students to the Risks and Advantages Based Statements About GM Food

The responses of teachers and students to the scientifically true statements on risks and advantages of GM food

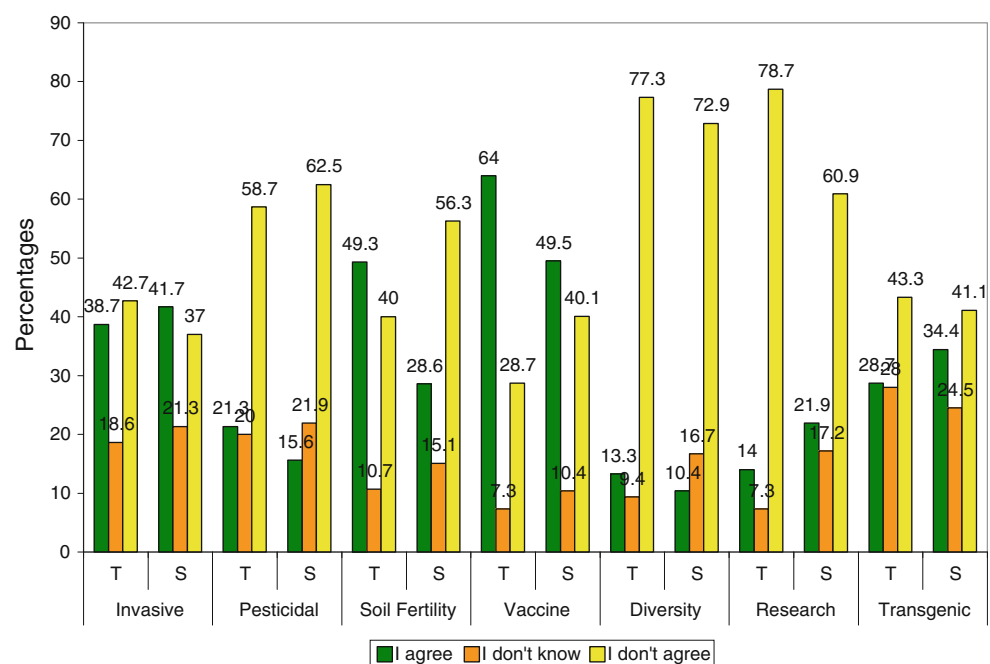
**Fig. 1** Responses of teachers and students to general statements about Genetically Modified Food



**Fig. 2** Responses of teachers and students to general statements about Genetically Modified Food



**Fig. 3** Responses of teachers and students to scientifically true statements about Genetically Modified Food

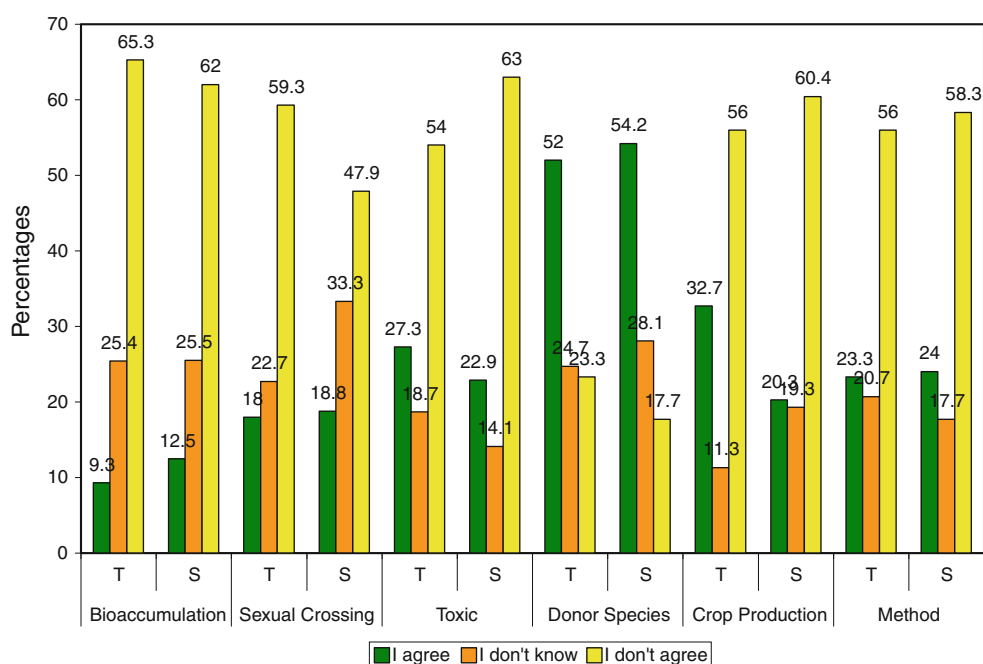


of section B of the questionnaire are plotted graphically in Figs. 3 and 4 and of non-scientific statements in Figs. 5.

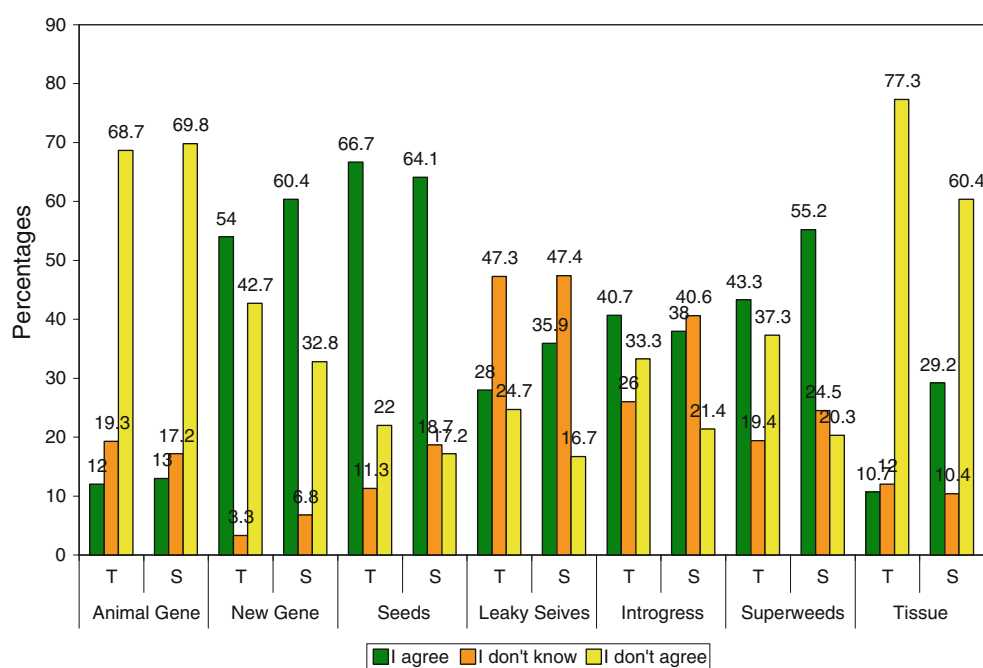
About three-fifth of the teachers and students (61.3% T and 58.3% S) were not aware of the fact that genetic modification of crops enhances an organism's ability to become an invasive species. Similarly, very less percentage of the teachers and students (21.3% T and 15.6% S) knew that plants engineered to produce proteins with pesticidal properties can affect non-target species. There was a remarkable significant difference between teachers and

students in affirming that genetically engineered crops deteriorate the soil fertility (49.3% T and 28.6% S,  $p < 0.01$ ) and vaccines and medicines developed through genetic engineering involve risk to human health (64.0% T and 49.5% S,  $p < 0.05$ ). Very few teachers and students (13.3% T and 10.4% S) had clear idea that genetically engineered crops released into environment will interact with diversity of habitat. There was little support in favour of research in developing medicines and vaccines through genetic engineering (14.0% T and 21.9% S,  $p < 0.01$ ).

**Fig. 4** Responses of teachers and students to scientifically true statements about Genetically Modified Food



**Fig. 5** Responses of teachers and students to scientifically false statements about Genetically Modified Food



Though there was no significant difference observed in affirming that transgenic viral resistant plants can lead to new viral diseases but more students (34.4%) than teachers (28.7%) agreed to it.

The results showed that ironically only few of our teachers and students have clear knowledge about the statements, pesticidal proteins produced by genetically engineered organisms have indirect effects through bioaccumulation (9.3% T and 12.5% S), sexual crossing of genetically modified crops with an existent weed species

can lead to the creation of more herbicide or disease resistant super-weeds (18.0% T and 18.8% S) and genetically modified food can lead to the production of toxic or allergic proteins (27.3% T and 22.9% S). However, about a little more than half of the teachers and students (52.0% T and 54.2% S) knew that the transgene takes on the nature of the organism to which it had been transferred and no longer retains any characteristics of donor species. Around one-third of the teachers (32.7%) and only one-fifth of the students (20.3%) agreed that farmers would be dependent

on agricultural biotechnology companies for seeds of GM crops which would lead to less control of crop production ( $p < 0.05\%$ ). The risk in GM food is related with the nature of the introduced genes and their products rather than the method used to improve the variety was understood only by one-fifth of the teachers and students (23.3% T and 24.0% S). Majority of teachers and students (68.7% T and 69.8% S) rightly rejected that if animal genes are inserted into plants, the plants would develop animal characteristics. However, many misconceptions are prevailing in the mind of teachers and students that genetic engineering is production of new genes (54.4% T and 60.4% S), that genetically engineered seeds can be saved to sow in the next season (66.7% T and 64.1% S), that all genetically modified plants are inherently leaky sieves (28% T and 35.9% S) that transgenes (genetically engineered genes) are more likely to introgress (enter) into wild species than mutated species (40.7% T and 38% S,  $p < 0.01$ ) and that creation of super-weeds is exclusively related to genetically modified plants (43.3% T and 55.2% S,  $p < 0.01$ ). Rather surprisingly, majority of teachers and students disapproved the statement that in genetic engineering genes are transferred from one tissue to another in the same organisms (77.3% T and 60.4% S,  $p < 0.01$ ).

#### Responses of Teachers and Students to the Open Ended Questions

Only 47% of the teachers correctly stated that the insertion of a gene(s) into a plant/animal to introduce a new characteristic or to alter an existing trait results in production of genetically modified crop/food while only 11% of the students could do that. Regarding consumption of GM food in our daily life, very few teachers could mention few names like tomato and rice while tomato is known to few students only. 84% of the teachers had no hesitation in eating bread made with yeast that has been genetically engineered in comparison to 63% of students. Majority of the teachers and students (88.5% T and 83.7% S) gave positive response when they were asked that should genetic engineering be used in production of food but at the same time many teachers expressed that the donor gene should be of a plant. Almost all students preferred GM food to be used to meet the requirements of the growing population while there was mixed response from teachers for organic, conventional and GM food for the same.

#### Discussion

While genetically modified foods remain a major source of controversy in many countries around the world, food

containing GM components are virtually everywhere. Several studies have elicited consumer stated preferences towards genetically modified foods in various countries around the world. Customarily, consumer stated preferences have been viewed as adequate proxies of potential response towards such products. Very few studies have been carried out to explore the knowledge and attitude of teachers and students on genetically modified foods. The findings presented in this study indicate that many concepts related with genetically modified food are not well understood neither by many of the teachers nor by the majority of students. Despite this, majority of the respondents (teachers and students) have well understood that genetic modification of an organism can be done by inserting a foreign gene into a plant or animal to introduce a new characteristic or to alter the existing trait and cross bred plants and genetically modified crops are not the same. The advantages of genetic engineering of both plants and animals most commonly affirmed by both teachers and students were improved storage properties and improved growth, although fewer students thought that these qualities were true of plant products. Rather few respondents thought that genetically engineered food would taste better or be cheaper than other foods, although many of the students in comparison to teachers gave neutral responses to statements about these issues, perhaps because they have no direct experience of such products. Similarly, not many teachers and students thought that food stuffs produced by genetic engineering would be healthier to eat, although less than half of the respondents saw such food as unsafe and can be fatal to humans. Similar findings have been reported by Hill et al. (1998), Dawson (2007), Seethaler and Linn (2004) and Saher et al. (2006) while studying the ideas of students about genetically engineered food-stuffs and biotechnology processes.

Majority of the respondents have affirmed that GM crops are high yielding, can save us from scarcity of food and are beneficial to farmers, but only about one half of the teachers and students expressed their preference for GM tomato over kitchen garden grown tomato. More teachers invoked religious argument in their thinking, suggesting that use of genetic engineering on cattle to make meat more nutritious should be banned. Surprisingly, they have no hesitation in taking GM food containing genes of animal origin but not human genes. About three-fifth of the teachers and students saw genetic engineering of organisms would cause risk to the environment but at the same time more than half of the teachers contradicted by affirming that GM organisms are not a threat to biodiversity and again majority of the respondents suggesting promotion of manipulation of genes for the production of better food. This results show clear-cut misconceptions prevailing in the mind of teachers and students about GM food. Most of



the studies in GM awareness and acceptance have focused on adult consumers despite youth comprising a significant consumer segment. Various studies have shown limited understanding of genetic engineering technique involved in the production of GM food (Sanbonmatsu and Fazio 1990; Falk et al. 2002; Fritz et al. 2002; Magnusson and Hursti 2002; Quan et al. 2002; Kalaitzandonakes et al. 2005).

Approximately, only two-fifth of the teachers and students realized that genetic modification of crops enhances an organism's ability to become an invasive species. However, many teachers and students were not aware of the fact that plants engineered to produce proteins with pesticidal properties can affect non-target species; that genetically engineered crops released into environment would interact with diversity of habitats; that it would deteriorate the soil fertility and affects ecosystem and that transgenic viral resistant plants can lead to new viral diseases. Hill et al. (1998) revealed that majority of British students accepted the idea that food stuffs produce by genetic engineering is safe for human health and thought that genetically engineered products should be labeled for product information. Different trends have been observed among the respondents of the present study. The results revealed that nearly three-fifth of the teachers and half of the students thought that vaccines and medicine developed through genetic engineering are unsafe for human health and research for developing these should not be supported. A number of misconceptions pertaining to effects of genetically engineered crops are prevailing in the mind of teachers as well as students. Majority of the respondents were not aware of the facts that pesticidal proteins produced by GM organism have indirect effects through bio-accumulation; that sexual crossing of GM crops with an existent weed species can lead to the generation of super weeds; that GM food can lead to production of toxic or allergic proteins and that risk in GM food is related with the nature of the introduced genes and their products rather than the method used to improve the variety.

The data of the present study clearly showed that a good number of teachers and students had very poor understanding of the technique involved in genetic engineering. This is well supported by the fact that many teachers and students thought that when animal genes are inserted into plants, they develop animal characteristics; that genetic engineering is production of new genes; and in genetic engineering genes are transferred from one tissue to another in the same organism. In contrast, many of the respondents gave neutral responses to the statements about leaky sieves nature of GM plants and introgression of transgenes.

The results of this study revealed the views of science teachers and senior secondary biology students about the application of a rapidly expanding technology, genetic engineering, to one particular purpose, food production.

Despite the high coverage of the issues surrounding the new biotechnologies in the popular media there is evidence that the knowledge base of the teachers and the students about genetic engineering remains somewhat insecure (Marlier 1992; Frewer et al. 1994 and Hill et al. 1998). The investigators think that in order to improve the students' knowledge, the teachers need to be equipped with appropriate knowledge and skills so that students would be able to make informed decision about the use of biotechnology and its products. Of course, we do not argue that science knowledge alone is sufficient; rather, we argue that knowledge provides a fundamental basis for informed decision making. There is evidence that explicitly introducing students to these topics will improve understanding and reduce uncertainty (Dawson and Schibeci 2003). For example, Lock et al. (1995) found that after 16 year old students in the UK were taught about biotechnology and genetic engineering (by trained teachers) their knowledge increased, attitude became more favourable and there was less uncertainty about their views. We would also argue that students need to be taught and explicit decision making skills if they are to make informed choices about genetic engineering (Dawson and Taylor 2000).

The application of genetic engineering in general could be considered as either personal or public (Dreyfus and Roth 1986; Hill et al. 1998). 'Personal' applications would be those in which only the individuals who make the decision are materially affected; gene therapy for diseases such as cystic fibrosis, or techniques for assisted pregnancy provide examples. 'Public' applications could be those which may have an effect on the environment or on the general public, without their consent or perhaps even knowledge. The release of genetically engineered organisms into the environment is an example; interestingly genetic engineering of food stuffs has elements of both the 'personal' and 'public' domains. On a 'personal' level, genetically engineered specific food items such as 'Flavr Savr' tomatoes are becoming more available. Here, provided items are labeled, individuals can choose whether or not to buy and consume such foods. The prevalent opinion that such decisions should be based on informed choices. On the other hand, genetically engineered food components such as Ciba Geigy's genetically engineered maize and soya are becoming widely used in a variety of foods. Furthermore, in the future it is likely that those items which are genetically engineered will be those which are most commonly used, so that returns on development investment can be maximized. Here, labeling becomes a problem, especially when primary suppliers provide a mixture of genetically engineered and non-engineered products. In this case, genetically engineered food stuffs become an example of the 'public' use of the technology because consumers may not be aware that food products contain

components derived from genetically engineered organisms. A further aspect in the same, ‘public’ arena is encapsulated in the question of whether genetically engineered crops and animals present a risk to the environment (Williamson 1996). This idea that genetically engineered organisms were an environmental threat was not held by many British students (Hill et al. 1998). In the present study, it was observed that many teachers and students strongly affirmed this view; they thought environmental damage by such organisms might be initially undetectable and ultimately irrevocable. In contrast, the ideas that genetically engineered crops released into environment will interact with diversity of habitat, deteriorate the soil fertility and affect the ecosystem, were not held by many of the teachers and students. This clearly reflects the poor understanding and the degree of confusion in the mind of students about genetic engineering.

Two other main themes emerged from the present results. Firstly, fewer students saw benefits, and more students saw disadvantages of genetically engineered animals than of vegetables while half of the teachers favoured both. Parallel findings have been revealed in older respondents who had more concern about application of genetic engineering to animals than to plants (Frewer et al. 1997). Secondly, teachers tended to be more cautious about the advantages and more aware of possible disadvantages of genetically engineered food stuffs than students.

## Conclusion

The results of the present study demonstrate that areas of insecure knowledge are present in many of the teachers and students. If we are to take seriously the proposition that the science curriculum must prepare future citizens (Solomon and Thomas 1990; Millar 1996; Jenkins 1999; Popli 1999) then some of the key science developments which feature regularly in the media should be included, modern biotechnology among them. Of course, we cannot expect science teachers to change the curriculum to accommodate these changes without support. Not all science teachers will have an understanding of modern biotechnology. More importantly, they may not feel comfortable dealing with science knowledge that has a controversial aspect. Clearly, professional development for science teachers is important here. The investigator feels that it is necessary to conduct training programmes effectively for science teachers not only to expose but also to understand the concepts/techniques of more rapidly expanding area of biology i.e. biotechnology.

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## References

- Dawson V (2007) An exploration of high school (12–17 year old) students’ understandings of, and attitudes towards biotechnology processes. *Res Sci Edu* 37(1):59–73
- Dawson V, Schibeci R (2003) Western Australian school students’ understanding of biotechnology. *Int J Sci Edu* 25:57–69
- Dawson V, Taylor PC (2000) Do adolescents’ bioethical decisions differ from those of experts? *J Biol Edu* 34:1–5
- Dreyfus A, Roth Z (1986) The consistency of the opinions of 12th grade biology pupils on the desirability of biotechnologies. *Res Sci Technol Edu* 4:139–152
- Falk MC, Chassy BM, Harlander SK, Hoban TJ, McGloughlin MN, Akhlaghi AR (2002) Food biotechnology: benefits and concerns. *Am soc Nutrition Sci* 132(6):1384–1390
- Fisher KM (1992) Improving high school genetics instruction. In teaching genetics: recommendations and research proceedings of a national conference, eds. Smith MU and Simmons PE pp 24–28. Cambridge
- Frewer LJ, Shepherd R, Sparkes P (1994) Biotechnology and food production—knowledge and perceived risk. *Brit Food J* 96:26–33
- Frewer LJ, Hedderley D, Howard C, Shepherd R (1997) ‘Objection’ mapping in determining age group and individual concerns regarding genetic engineering. *Agric Hum Values* 14:67–79
- Fritz S, Husmann D, Wingenbach G, Rutherford T, Egger V, Wadhwa P (2002) Awareness and acceptance of biotechnology issues among youth, undergraduates and adults. *J Agrobiotechnol Manag Econ* 6 (4), article 5
- Garton GL (1992) Teaching genetics in the high school classroom. In teaching genetics: recommendations and research proceedings of a national conference, eds. Smith MU and Simmons PE pp 20–23. Cambridge
- Hallman WK (1996) Public perceptions of biotechnology: another look. *BIO/TECHNOLOGY* 14:35–38
- Hill R, Stanistreet M, Boyes E, Sullivan O (1998) Reactions to a new technology: students’ ideas about genetically engineered food-stuffs. *Res Sci Technol Edu* 16(2):203–216
- Hoban TJ (1997) Consumer acceptance of biotechnology: an international perspective, nature biotechnology. *Nat Biotechnol* 15:232–234
- Hoban TJ, Kendall PA (1992) Consumer attitudes about the use of biotechnology in agriculture and food production. North Carolina State University, Raleigh, NC, USA
- Holdredge C, Talbott S (2001) Sowing technology: the ecological argument against genetic engineering down on the farm. *Sierra: the magazine of the Sierra Club*, 24–72
- Jenkins EW (1999) School science, citizenship and the public understanding of science. *Int J Sci Edu* 21:703–710
- Kalaitzandonakes N, Marks LA, Vickner SS (2005) Sentiments and acts towards genetically modified foods. *Int J biotechnol* 7(1–3): 161–177
- Kindfield ACH (1992) Teaching genetics: recommendations and research. In teaching genetics: recommendations and research proceedings of a national conference, eds. Smith MU and Simmons PE pp 39–43. Cambridge
- Kirkpatrick G, Orvis K, Pittendrigh B (2002) A teaching model for biotechnology and genomics education. *J Biol Edu* 37(1):31–35
- Lewis J, Wood-Robinson C (2000) Genes, chromosomes, cell division and inheritance—do students see any relationship? *Int J Sci Edu* 22:177–195



- Lock R, Miles C (1993) Biotechnology and genetic engineering: students; knowledge and attitudes. *J Biol Edu* 27:267–273
- Lock R, Miles D, Hughes S (1995) The influence of teaching on knowledge and attitudes in biotechnology and genetic engineering contexts: implications for teaching controversial issues and the public understating of science. *School Sci Rev* 76:47–59
- Losey J, Raylor R, Carter M (1999) Transgenic pollen harms monarch larvae. *Nature* 399:214
- Macer D (1994) Bioethical reasoning of students in Singapore and Hong Kong Bioethics for the people by the people. Ethics Institute, 165–169
- Magnusson MK, Hursti UK (2002) Consumer attitudes towards genetically modified foods. *Appetite* 39(1):9–24
- Marbach-Ad (2001) Attempting to break the code in student comprehension of genetic concepts. *J Biol Edu* 35(4):183–189
- Marchant R, Marchant EM (1999) G M plants: concepts and issues. *J Biol Edu* 34:5–12
- Marlier E (1992) Euro barometer 351-: opinions of Europeans on biotechnology in 1991. In: Durant J (ed) *Biotechnology in public: a review of recent research*. Science Museum Publications, London
- Millar R (1996) Towards a science curriculum for public understanding. *School Sci Rev* 77:7–18
- Popli R (1999) Scientific literacy for all citizens: difference concepts and contents. *Public Understand Sci* 8:123–137
- Quan L, Curtis KR, McCluskey J, Wahl TI (2002) Consumer attitudes towards genetically modified foods. *J Agro Biotechnol Manag Econ* 5(4):145–152
- Saher M, Lindeman M, Hursti UK (2006) Attitude towards genetically modified and organic foods. *Appetite* 46(3):324–331
- Sanbonmatsu D, Fazio R (1990) The role of attitudes in memory-based decision making. *J Pers Soc Psychol* 59(4):614–622
- Seethaler S, Linn M (2004) Genetically modified food in perspective: an inquiry based curriculum to help middle school students make sense of trade offs. *Int J Sci Edu* 26(14):1765–1785
- Solomon J, Thomas J (1990) Science education for the public understanding of science. *Stud Sci Edu* 33:61–90
- Stewart BJ (1987) Genetics in relation to biology. *School Sci Rev* 68:645–653
- Stewart JH, Van Kirk J (1990) Understanding and problem solving in classical genetics. *Int J Sci Edu* 12:575–588
- Tada Y, Nakase M, Adachi T, Nakamura R, Shimoda H, Takahashi M, Fujimura T, Matsuda T (1996) Reduction of 14–16 kDa allergenic proteins in transgenic rice plants by antisense gene. *FEBS Lett* 391:341–345
- Thayer A (1999) Transformic agriculture: transgenic crops and the application of discovery technologies are altering the agrochemical and agricultural business. *Chemical and Engineering News*, 19 April, 21–35
- Williamson M (1996) Can the risk from transgenic crop plants be estimated? *Tibtech* 14:449–450
- Wolfenbarger L, Phifer P (2000) The ecological risks and benefits of genetically engineered plants. *Science* 290:2088–2093
- Ye X, Al-Babali S, Kloti A, Zhang J, Lucca P, Beyer P, Potrykus I (2000) Engineering the provitamin- A ( $\beta$ -carotene) biosynthetic pathway into (carotenoid free) rice endosperm. *Science* 287(5451):303–305
- Yoon C (1999) Stalked by deadly virus, papaya leaves to breed again. *The New York Timer*, 20 July
- Zechenedorf B (1994) What the public think about biotechnology. *BIO/TECHNOLOGY* 12:871–875